

AD/A-002 711

POLARIZING FILTERS AND UNDERWATER  
VISION

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Groton, Connecticut

29 May 1974

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AD/A002111

## DOCUMENT CONTROL DATA - R &amp; D

Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified

1. ORIGINATING ACTIVITY (Corporate author)		2a. REPORT SECURITY CLASSIFICATION	
NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY		Unclassified	
		2b. GROUP	
3. REPORT TITLE			
POLARIZING FILTERS AND UNDERWATER VISION			
4. DESCRIPTIVE NOTES (Type of report and inclusive dates)			
Interim report			
5. AUTHOR(S) (First name, middle initial, last name)			
S. M. Luria and Jo Ann S. Kinney			
6. REPORT DATE		7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
29 May 1974		5	7
8a. CONTRACT OR GRANT NO.		9a. ORIGINATOR'S REPORT NUMBER(S)	
8b. PROJECT NO.		NSMRL Report Number 783	
M4306.03-2050DXC5.18			
c.		9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
d.			
10. DISTRIBUTION STATEMENT			
Approved for public release; distribution unlimited.			
11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY	
		Naval Submarine Medical Rsch. Lab. Box 900, Naval Submarine Base Groton, Connecticut 06340	
13. ABSTRACT			
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(14)

DD FORM 1473 (PAGE 1)

5/N 0102-014-6600

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NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY  
REPORT NUMBER 783

Bureau of Medicine and Surgery, Navy Department  
Research Work Unit M4306.03-2050DXC5.18

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## SUMMARY PAGE

### THE PROBLEM

To determine the practical utility of polarizing filters for improving visibility under water.

### FINDINGS

Visibility changes as a function of the orientation of the axis of a polarizing filter, but it is better without the filter. Under dimmer artificially polarized light, visibility is considerably degraded when observing through a filter.

### APPLICATION

These results do not indicate that polarizing filters are of practical value in improving visibility under water either under natural light or artificially polarized light.

### ADMINISTRATIVE INFORMATION

This investigation was conducted as part of Bureau of Medicine and Surgery Research Unit M4306.03-2050DXC5. The present report is Number 18 on this work unit. It was submitted for review on 29 March 1974, approved for publication on 29 May 1974 and designated as NavSubMedRschLab Report No. 783.

PUBLISHED BY THE NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

## ABSTRACT

The effectiveness of polarizing filters in improving resolution acuity and detection thresholds under water was measured both in sunlight and under polarized artificial light. The magnitude of natural polarization of sunlight is enough to affect the thresholds as the observer's polarizing filter is rotated, but vision with the filter is not reliably superior to that without the filter. In dimmer artificial light, the reduction in the amount of light reaching the eye through the filter outweighs any beneficial effects of the polarization phenomenon and visibility is decreased.

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# POLARIZING FILTERS AND UNDERWATER VISION

## INTRODUCTION

Natural light is polarized. This phenomenon is clearly observable with the polarizing filters found in many sunglasses. The degree of polarization depends on the angle formed by the observer's line of sight to a point in the sky and the line from that point to the sun - the angle of scatter as it is called. As illustrated in Fig. 1, direct sunlight is unpolarized, but the light reflected from molecules of air is partly polarized.

Skylight entering the water also exhibits various degrees of polarization, again depending on the angles of scatter.<sup>1</sup> This is also readily observable. Consequently, it is believed that the polarization of light is used as a navigational aid by both airborne and marine animals.<sup>2</sup>

The question of whether the polarization of light in the water can be used to improve the vision of divers has been raised by several investigators. Theoretically, it can, because light reflected from large objects maintains its polarization, but light reflected from the tiny particles suspended in the water does not. Thus, a polarizing filter should be able to transmit the light from the large objects while screening out much of the veiling light present in the water. It is not certain if this is a practical proposal, however, because the ambient light in the water is not polarized very much. Nevertheless, Lythgoe and Hemmings<sup>3</sup> have reported increasing the range at which targets

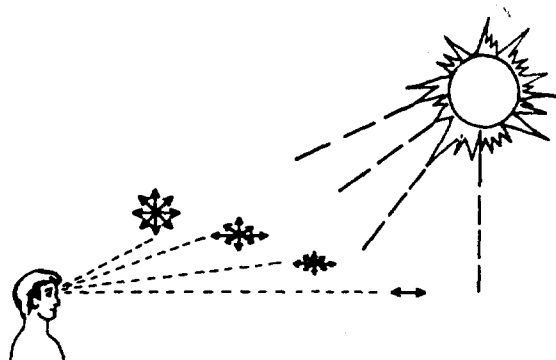
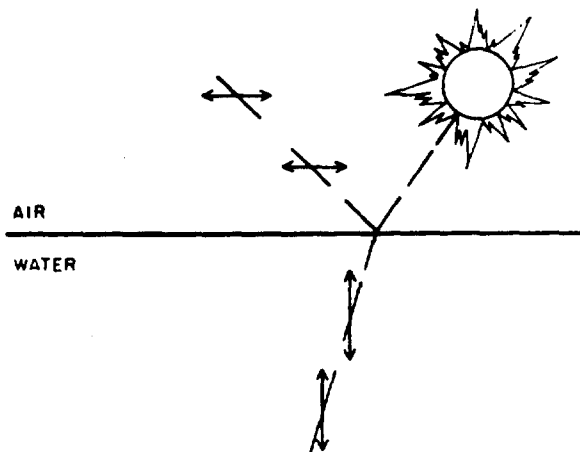


Fig. 1. The degree of polarization depends on the angle formed by observer's line of sight to a point in the sky and the line from that point to the sun.



Reflection from the surface of the water produces polarization in both the reflected and refracted rays, but in planes which are perpendicular to each other.

became invisible with the use of polarizing filters.

It would appear, however, that using polarizing filters in conjunction with artificial light which has itself been polarized would hold far more promise of success. And, indeed, Briggs and

Hatchett<sup>4</sup> as well as Gilbert and Pernicke (cited in Mertens<sup>1</sup>) have reported improving visibility by this method, the latter by a substantial amount.

This study was carried out to check these findings. It sought to determine whether or not there is a difference in the distance at which a target can be seen (1) as a function of the axis of the polarizing filter before the observer, and (2) whether visibility with optimal filter-orientation is better than that with no filter at all. Measurements were carried out in three bodies of water with different levels of turbidity. Both resolution acuity thresholds and detection thresholds were obtained. Measurements were taken both in natural light and under artificially polarized illumination.

#### EXPERIMENT I - Natural Light

The first experiment was carried out in two turbid lakes with somewhat different degrees of turbidity. All measurements were made on sunny days within 90 minutes of noon. Thresholds were obtained for four subjects in the clearer lake ( $\alpha = \text{ca. } 4$ ) and for two subjects in the more turbid lake ( $\alpha = \text{ca. } 8$ ). Measurements were taken for three orientations: looking away from the sun, toward the sun, and with the sun's rays perpendicular to subject's line of sight.

#### Method

##### Polarizing filters

Linear polarizing filters, 18 cm square, made by the Polaroid Corp.,

were used. Each filter transmitted 40% of the incident light through the horizontal axis and 20% through the vertical axis. When crossed, the pair transmitted about 4% of the light.

##### Targets and Apparatus

Three targets were used in this experiment. All were 18 cm square. One was a grid with alternating black and gray stripes 3 cm wide. The contrast was .48, calculated by the formula  $L_H - L_L / L_H + L_L$  where  $L_H$  is the higher luminance and  $L_L$  is the lower luminance. The other targets were a white square and a black square.

The targets were presented to the subject in a holder which could be moved back and forth along a graduated horizontal rod. The rod was attached to a heavy tripod which supported S's chinrest. The distance of the target from S could be read from the rod.

##### Procedure

Observations were made in water 4 ft deep with S wearing a standard SCUBA facemask<sup>5</sup> and snorkel. S knelt with his chin in the chinrest and looked along the horizontal rod while holding the polarizing filter against his SCUBA mask. (S did not know the axis of the filter.) Thresholds were measured with the method of limits. The target-holder was moved slowly away from S until he signalled that he could no longer see it (in the case of the white or black target). It was then moved slowly toward S until he signalled that it was again visible. Four to eight such measurements were taken for each threshold, depending on S's variability. In the case of the grid



target, S was required to indicate the orientation of the stripes (horizontal or vertical). Each orientation was presented half the time, in random order.

### Subjects

All subjects were staff members of the laboratory.

### Results

The first question was whether or not there is enough natural polarization of sunlight to produce differences in threshold as a linear polaroid filter is rotated before the eyes. Table I gives the mean distances at which four Ss in the less turbid lake and two Ss in the more turbid lake could correctly indicate the correct orientation of the grid target. The results are quite clear. Visibility thresholds were appreciably better when the axis of the polarizing

filter was vertical irrespective of S's orientation with respect to the sun.

For example, in the less turbid lake with the sun in back of S, the grid target could be resolved at a mean distance of 95.3 cm with a vertical filter but only 83 cm with a horizontal filter. This effect occurred for every S in every condition. The difference in turbidity between the two bodies of water is evident in the two sets of threshold distances, but the pattern of results was the same in both cases.

The results with the white and black targets were not so clear cut. All the Ss reported the appearance of the white target at a farther distance through the vertical filter when the sun was either in back of them or to their side. But when looking toward the sun, the Ss were not consistent. The data from the two lakes have been combined in Table II. The distances are relatively large

Table I. Mean resolution threshold distance (cm) for grid target seen through a horizontal or vertical polarizing filter for various orientations of S with respect to sun.

	Less Turbid Lake (N=4)		More Turbid Lake (N=2)	
	Horizontal	Vertical	Horizontal	Vertical
Sun at back	83.0	95.3	36.4	39.0
Sun at left	69.8	74.0	25.5	25.9
Looking toward sun	59.1	69.9	17.3	21.8

because more Ss were tested in the less turbid lake and because the detection distances for the white target were much greater than the distance at which the grid target could be resolved.

With the black target, the Ss were not consistent under any of the conditions; under each condition, one S showed better visibility with the horizontal filter. In addition, the differences in threshold between the horizontal and vertical filters were very small. The data from the two lakes are again combined in Table III.

The improved visibility of the grid and the white target through the vertical filter indicates that the polarization phenomenon was effective. Since light is polarized vertically in the water, the vertical filter should pass the light from the target while screening out the more unpolarized radiation in the background. Moreover, the polarization effect would seem to be substantial, since more light is actually transmitted through the horizontal axis and yet visibility was greater through the vertical axis.\*

These results show that the degree of natural polarization of light is sufficient to produce differences in visual

Table II. Mean detection threshold distances (cm) for a white target seen through a horizontal or vertical polarizing filter for various orientations of S with respect to the sun.

	Horizontal	Vertical
Sun at back	100.8	109.0
Sun to left	58.5	61.3
Toward sun	68.2	67.8

Table III. Mean detection threshold distances (cm) for a black target seen through a horizontal or vertical polarizing filter for various orientations of S with respect to the sun.

	Horizontal	Vertical
Sun at back	69.8	70.4
Sun to left	69.8	68.6
Toward sun	66.0	68.0

\*To further demonstrate the polarizing effect, the acuity of four Ss was measured in air through the filter. Resolution thresholds were measured with a set of high-contrast grids of varying bar-widths using the method of constant stimuli. In air, mean acuity was better through the horizontal filter (1.75) than through the vertical filter (1.67), the opposite of what was found in the water.

thresholds as a result of the orientation of a linear polarizing filter. The vertical orientation of the filter is better in the water.

The next question was whether or not the polarizing filter in its optimal

orientation improves visibility compared to no filter at all. This was tested only in the less turbid water with the Ss looking away from the sun. The results are given in Table IV. It was clear that the use of the filter did not result in much improvement in visibility. Only with the white target was the mean visibility threshold better with the filter, and that difference was minimal.

Table IV. Mean threshold distances (cm) for various targets viewed through either a vertical polarizing filter or no filter while facing away from the sun.

Target	Vertical	No Filter
Grid	85.5	88.0
White	109.0	108.0
Black	94.0	96.0

## EXPERIMENT II - Artificial Light

Next we tested whether visibility through a polarizing filter would be significantly improved if the source of illumination were also polarized. It is no trouble, of course, to produce artificially a magnitude of polarization which far exceeds that found naturally. This experiment compared visibility through a polarizing filter with unfiltered visibility when the ambient illumination was artificially polarized.

## Method

### Filters and Light

The experiment was conducted in an indoor swimming pool at night. The water was clear enough so that the divers could see the length of the 75-ft pool with overhead illumination. To carry out this experiment, however, the overhead lights were turned out and illumination in the pool was provided solely by an underwater mercury light, Model L2B, manufactured by the Oceanographic Engineering Corp. A linear polarizing filter with vertical axis could be attached to the lamp housing. A similar polarizing filter positioned in front of the S's facemask with the axis either horizontal or vertical. The lamp was located to S's left so that the angle formed by the lines of sight from the target to the lamp and from the target to S was about 30°.

### Targets

Two different types of targets were used. The first was a set of high contrast (.66) black and white grid targets whose bar-width ranged from .66 to 2.22 mm. In addition, a dark gray circle of 3 cm diameter on a light gray square 7 cm on a side was used. The contrast, calculated by the same formula as before for purposes of comparison, was .24.

### Procedure

The S knelt in 4 ft of water with the mask, filter, and snorkel. The targets were presented at a distance of 12 ft. Resolution thresholds were measured by the method of constant stimuli. A set of

about five targets was selected which bracketed S's acuity. The targets were presented in random order, making certain that the vertical and horizontal orientations were each presented half the time. Each target was presented six times. The percentage of correct responses was plotted on cumulative probability paper and the point of 50% correct responses taken as threshold. Thresholds were measured with the axis of the diver's polarizing filter in the same orientation as that before the lamp, with the axes crossed, and with no filter before S's facemask.

In addition, thresholds were measured with the low contrast circle using the method of the first experiment: the circle was slowly moved toward and away from S and its distance from S noted when it became visible or invisible.

### Results

Table V gives the acuity thresholds (1/visual angle in min) under the various conditions for two Ss. Acuity was good without the filter, as would be expected in clear water,<sup>6</sup> and substantially better than when S viewed the targets through a polarizing filter. When the orientation of the axis of S's filter was the same as that before the lamp, acuity declined. When the axes of the two filters were crossed, acuity declined still further.

In one final test, the detection threshold for the low contrast circle was measured under these conditions for a severely myopic subject. The distances at which he could detect the circle are also given in Table V. The results

conform completely with the resolution thresholds. With no filter before his mask, S could detect the circle at a mean distance of 2.74 m. When the axis of his filter was in the same orientation as that of the lamp filter, the mean detection distance was 2.29 m; with the axes crossed, it fell further to 1.98 m.

### DISCUSSION

These results show, first of all, that the degree of natural polarization is enough to produce differences in target-visibility as the axis of a diver's polarizing filter is rotated. Resolution thresholds were sensitive to this variable irrespective of the location of the sun in relation to the diver. Detection thresholds for white targets were better with the properly oriented filter when the sun was behind the diver or to his side. There was no difference, however, when looking toward the sun. Under this condition, of course, the "white" target was reduced to a black silhouette and the results were similar to those with the black target; the latter showed no threshold differences as a function of filter orientation, irrespective of the position of the sun.

Despite these positive findings, the comparison of target-visibility with and without the polarizing filter does not suggest that the polarization phenomenon has a great deal of practical utility. In the sunlight, target-visibility without the filter was, if anything, slightly better than with the filter in its optimal orientation. When an attempt was made to maximize the polarization phenomenon by polarizing an artificial light-source,

Table V. Mean acuity thresholds for grid targets and distance thresholds (meters) for circle in artificially polarized light as a function of orientation of S's polarizing filter.

	Visual acuity		Distance (m)
	Subj: TP	Subj: JK	Subj: MS
No filter	1.45	1.11	2.74
Same axes	0.82	0.81	2.29
Crossed axes	0.70	0.70	1.98

there was a great decline in both acuity and detection when the diver looked through a polarizing filter. The reason must be that the filter reduces the amount of light reaching the eyes. In bright sunlight, where visual acuity has reached the plateau of the acuity-luminance function,<sup>7</sup> this reduction has only small, if any, effects on acuity. Under the much dimmer artificial illumination, these reductions in luminance lead to appreciable decreases in acuity.

These results do not conform, of course, with the studies cited above which reported positive findings with polarizing filters. However, it will be noted that Briggs and Hatchett<sup>4</sup> were concerned primarily with the improvement of photographic and television images. They pointed out that techniques which are effective with such equipment are not necessarily effective in improving unaided vision. They noted that their results were achieved by matching the elements of the video system to the problems

peculiar to the underwater environment, and the human eye is not subject to such modification.

Their report of improved visibility with polarizing filters was made very briefly in passing, and they stated that their results were "not conclusive, since there were some basic faults in the experimental setup" (p. 1304).

Lythgoe and Hemmings studied both visual perception and photographic effects. Although their photographs show a clear effect, their data for a human observer seem to show that the polarizing filters were useful for targets only of intermediate (15-30%) reflectance. Their data for targets of both smaller and greater reflectance show little, if any, difference between distance thresholds with and without the filter.

The paucity of reports of positive findings suggests at least a difficulty in obtaining such improvements, if

not the existence of a greater number of negative, unpublished results.

As a final practical consideration, it should be borne in mind that polarizing filters, even if effective, would require a constant orientation. This might not always be maintained by a free-swimming diver and would therefore reduce his effectiveness.

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